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Effect of interstitial filling, ball and feed size on particle breakage in a laboratory ball mill: An Attainable Region technique

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Abstract

The interstitial filling, grinding media and feed particle size are vital parameters to be considered during ball mill operation. Experiments were conducted to ascertain whether there are possible interactions between the three variables and the fineness of the required product. The data obtained was analysed using the Attainable Region (AR) optimization method which is a model-free and equipment-independent tool. Experimental results indicate that there is a need to adjust or correlate powder filling with grinding media and feed particle size. It is of paramount importance to find optimal operational parameters for these variables during ball mill operations. The AR technique helps identify opportunities to save engineers significant time, reduce operation costs and consequently allow them to get closer to the objective of optimum plant operation that would result in achieving product requirements.

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1. Introduction

In Zimbabwe the platinum-group metals (PGMs) are found in the Great Dyke; a large intrusion of igneous rocks that roughly runs across the centre of the country from the north to the south over an approximate distance of 550 kilometres. Although geometrically different, the Great Dyke has a lot of similarities in terms of geological formations with the South African Bushveld Complex. The main difference between the mineral deposits in the Bushveld Complex and those in the Great Dyke is that South Africa's Bushveld deposits are at an advanced stage of development. Many operations have reached a level of maturity, which is rendering them uneconomic to operate at their current depths and forecasted metal prices. On the other hand, the Great Dyke is barely touched and therefore represents a much shallower and more cost-effective ore body for PGMs production. Herein lies an opportunity for Zimbabwe to be a major supplier of PGMs.

The size reduction of mineral ores, chemical reagents and pharmaceutical compounds is important in many different types of industries. For example in the mineral processing industry, ore particles are broken into smaller particles to increase the degree of liberation that results in the creation of a new surface, shape and size for downstream concentration or recovery processes. Once that is achieved, it is possible to obtain optimum extraction and separation of the value mineral from gangue material. Any potential savings realised in this field encourage research and development efforts targeted towards the optimization of grinding

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mills. In the past few years, the depletion of mineral ore grades has seen mineral processing engineers resorting to increasing tonnages in their operations though not scaling up in their mining equipment. Treating higher tonnages sometimes results in a slight increase in profits though the efficiency of unit operations is compromised. An example is the energy intensive ball milling operation. Charging the mill with a higher tonnage has some significant effects on the efficiency of this reactor vessel which prepares material for downstream concentration unit operations. Adding more feed material translates to an increase in amount of powder and interstitial filling (U) in the mill.

Austin [1] defines U as the fraction of the spaces between balls at rest that is filled with ore material. A number of researchers have obtained different values of U depending on the ore characteristics [2-7]. The concept of interstitial filling has therefore gained more attention in the past few years though all the extremes of U from minimum to maximum have not been explored.

This work attempts to look at the relationship between the interstitial filling, grinding media and feed particle size on the breakage of a PGM ore. A model free tool called the Attainable Region (AR) technique which is an optimization tool firstly used in the reactor optimization will be used to optimise particle breakage. The tool has been defined as a set of all possible outputs, for any system under consideration, that can be attained using the fundamental processes operating within the system and that satisfies all constraints placed on the system [8, 9]. The construction and use of the tool to investigate various factors has been discussed by a number of researchers [10-14].

2. Materials and Methods

A PGM ore was obtained from a local platinum mine in Zimbabwe and analysis of the material revealed that it is composed of complex silicates, and the proportions of silicates, oxides, sulphides and precious metals are shown in Table 1 and 2.

Table 1: Metal analysis of feed ore material

Element	Concentration (ppm)
Pt	1.76
Pd	1.39
Rh	0.18
Ir	0.1
Au	0.3

Table 2: Relative proportions (by mass) of oxides, sulphides, and silicates

Phase	Feed %	Tailing %
Oxides	0.3	0.2
Sulphides	1.5	0.7
Silicates	98.2	99.1

Source: [15]

Two feed sizes, a coarse and a finer class (-2360+1700 μ m and -850+600 μ m respectively) were prepared as samples for the grinding mill experiments. We then rifle split the material into 500g analysis sample which were then used as analysis feed to the mill. A ball load of J = 0.2 and ball sizes of diameter 10 and 30 mm were used as charge for the mill. Interstitial values of 0.5, 0.75, 1.0, 1.5 and 2.0 were used in order to span the range from low to high and also evaluate the grinding fundamental behind each U. In this work, seven mill durations were considered: 3, 5, 10, 15, 20, 30 and 45 minutes. The charge was ground and then analysed with full PSD done on the product. A new, fresh material sample was then charged, ground for the next grinding time and then analysed. The procedure was repeated until the last sample ground for 45 minutes was analysed.

Table 3: Particle size class specifications used for AR analysis

Size class	Upper (microns)	Lower (microns)
Courser Feed		
M1 (Feed)	2360	1700
M2 (intermediate)	1700	850
M3 (fine)	850	Pan
Finer Feed		
M1 (Feed)	850	600
M2 (intermediate)	600	212
M3 (Fine)	212	pan

Table 3 shows particle size specifications used to apply the AR method.

3. Results and Discussion

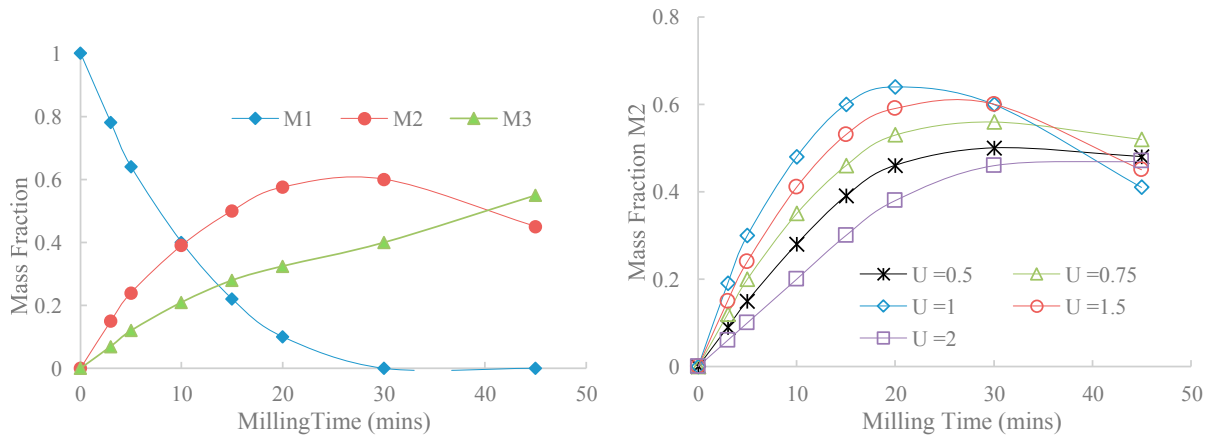


Figure 1(a) Mass fraction of material in the size class 1, 2 and 3 vs. the grinding time (ball size 30 mm; particle size 2360-1700 μ m; U =1.5) (b) Mass fraction M2 vs. the milling time (ball size 30 mm; particle size 2360-1700 μ m)

Figure 1 depicts the trend that has always been obtained during size reduction processes. Feed material breaks into smaller size classes. The amount of material that reports to a certain class is of vital importance. Downstream processes like leaching, flotation will require different particle sizes or degrees of liberation. The mode of breakage (impact, chipping or attrition) is influenced by a number of factors. One of these being the relationship between the ball and feed particle size. On the other hand, the powder filling will affect the product fineness when changed in relation to ball and feed particle size

Figure 1(b) shows Policy I, where a larger ball size added to a relatively large size ~ 1 mm has an optimal U =1. This shows that large grinding media are able to impact the feed having the right size. The results show that the diameter of the balls is an important parameter in relation to the feed size. These larger balls promote impact breakage hence more material reports to the intermediate size class. An interstitial filling of 0.75 and 1.5 gives a much lower amount of breakage. As U increases the cushioning effect also increases. On the other hand low values of U favour ball to ball interactions hence a reduction in impact energy due to steel to steel interactions and ultimately less breakage. With a high value of 2 the cushioning effect increases and rates of breakage are lowered.

Figure 2(a) shows Policy II, where a large ball size is used to grind a relatively small feed size ~ 1 mm. In this case it is observed that somehow less breakage is observed for smaller U values. Higher values on the other hand show an improvement in particle breakage. A probable explanation for this trend is that breakage shifts from impact to abrasion as particle size increases. Large particles easily break a large feed size mostly through impact breakage whilst the same large particles are unable to break smaller particles through impact breakage but through abrasion. Theory suggests that smaller particles are much stronger as larger

Griffith flaws exist in larger ore particles and can be broken much easier during size reduction processes. An interstitial filling value of 2.0 still gives the lowest amount of required PSD. Low values of U cause ball to ball interactions leading to loss of energy and excessive wear of grinding media.

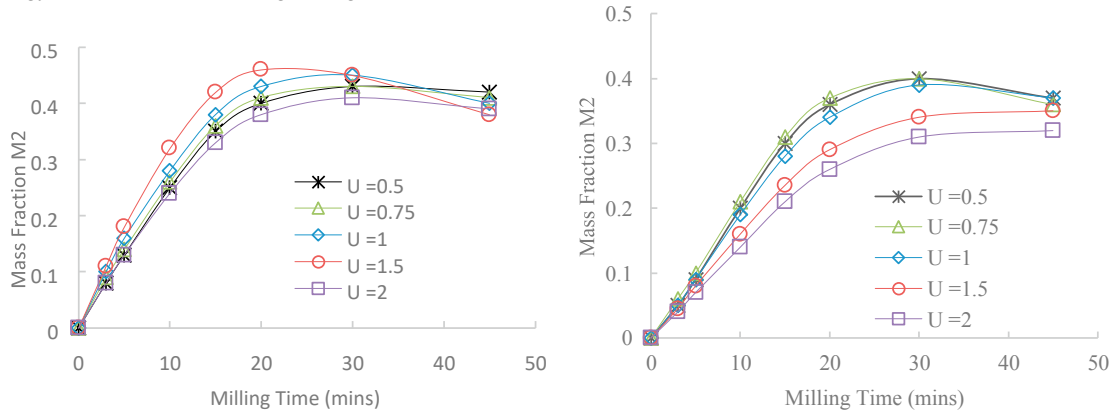


Figure 2: Mass fraction M2 vs. the milling time (a) ball size 30 mm; particle size 850-600µm (b) ball size 10 mm; particle size 2360-1700µm

Figure 3 shows Policy III, where a small ball size is used to grind a relatively large size ~ 1 mm. In this case it is observed that breakage is very low as attrition (compared to impact breakage) plays a prominent role. The grinding media cannot sufficiently nip the ore particles and hence cause breakage. Higher values of U give even poorer breakage rates as the grinding media offers less surface area for breakage.

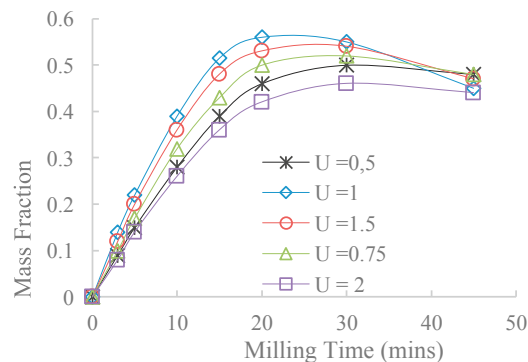


Figure 3: Mass fraction M2 vs. the milling time (ball size 10 mm; particle size 850-600µm)

Figure 3 shows Policy IV, where a small ball size is used to grind a correspondingly small feed size ~ 1 mm. The graph shows that the selected grinding media size offers better breakage rates for smaller compared to large particles. Improved rates are observed for a U value ~ 1 . Higher values offer better breakage rates due to attrition breakage that is prominent.

4. Conclusion

Dry grinding tests were conducted using a PGM ore sample to evaluate possible interactions between ball size, particle size and interstitial filling. The work involved studying all extremes of U from minimum to maximum to completely describe the AR. The concept of U as applied to AR was explored and the results show that there is a significant advantage of correlating the three variables and therefore it is of paramount importance to explore the grinding fundamental behind each U . Because of the complete range of types of breakage (impact or attrition) present in a mill charged with grinding media, chances are each of the mechanisms will overlap, forming a continuum of breakage actions. A $U \sim 1$ is seen to be ideal for grinding with relatively large balls vs. large feed size > 1 mm. When the feed size becomes too small to be impacted by crushing forces, one moves to a region of abrasion which is assisted by greater values of U . The work showed that the benefits of studying U could be the maximization of intermediate sizes depending on product specification. Each material must therefore be evaluated in order to obtain the optimal variables to lower the energy costs in the grinding process.

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